Investigation of Ni-Gate Defects in AlGaN/ GaN HEMTs

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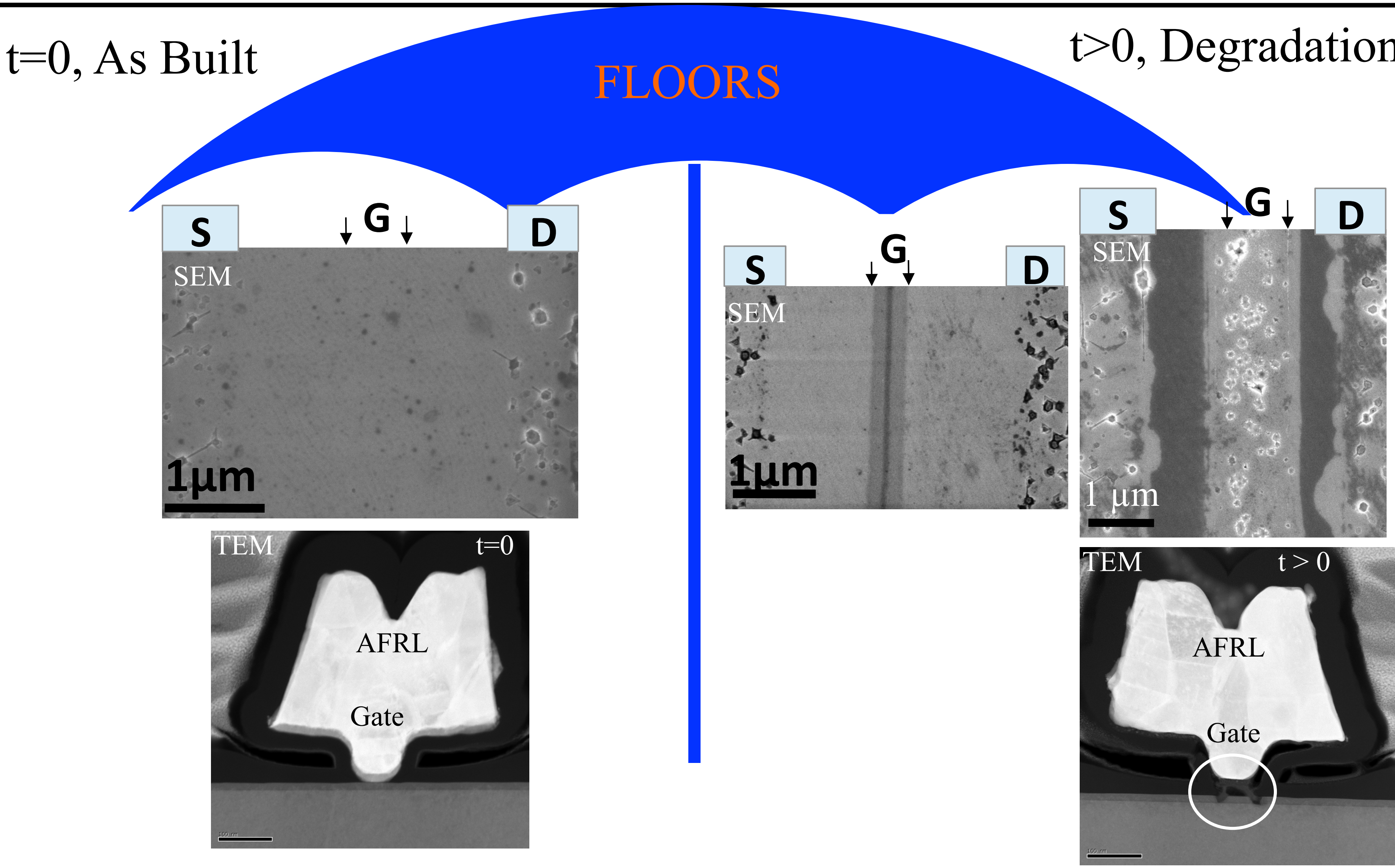
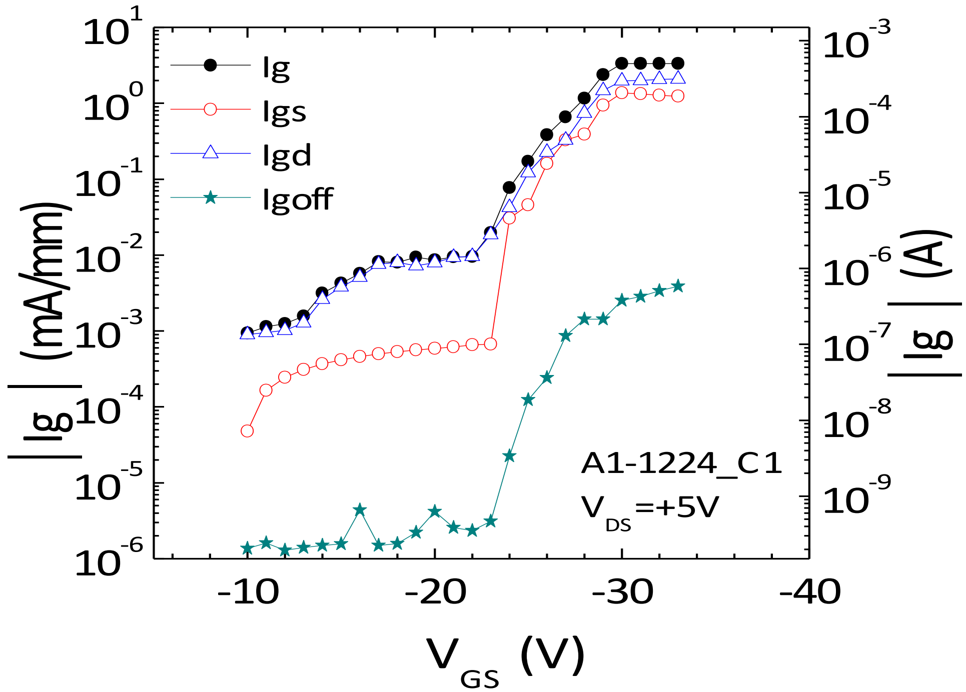
SEM and TEM of Under Gate Defects



Outline

- **Introduction**
  - Electrical Stressing vs. Thermal Stressing
- Deprocessing Method
- Experimental Method
- Gate Current Leakage
  - Banding Defects
  - Pitting Defects
- Conclusions

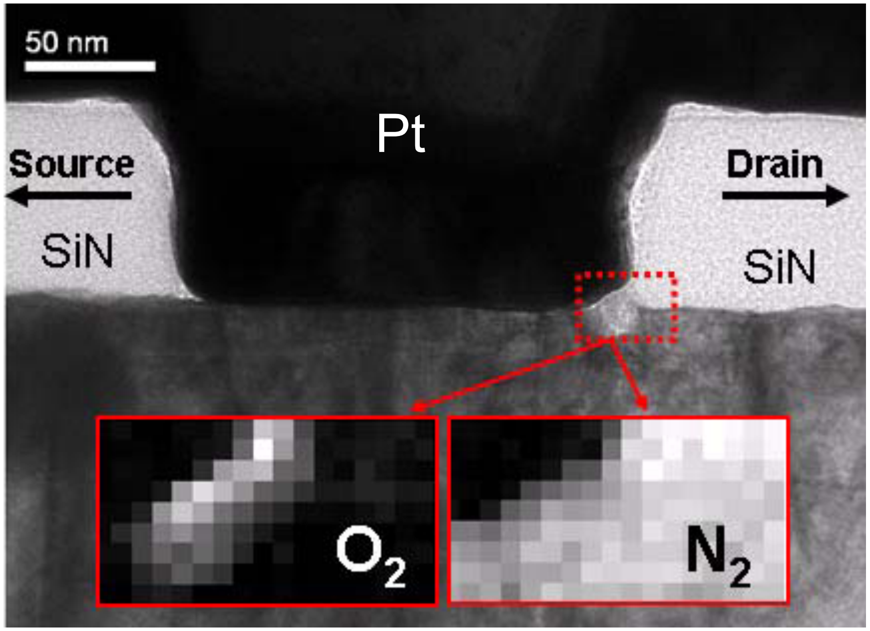
Typical Off-State Electrical Stress Result



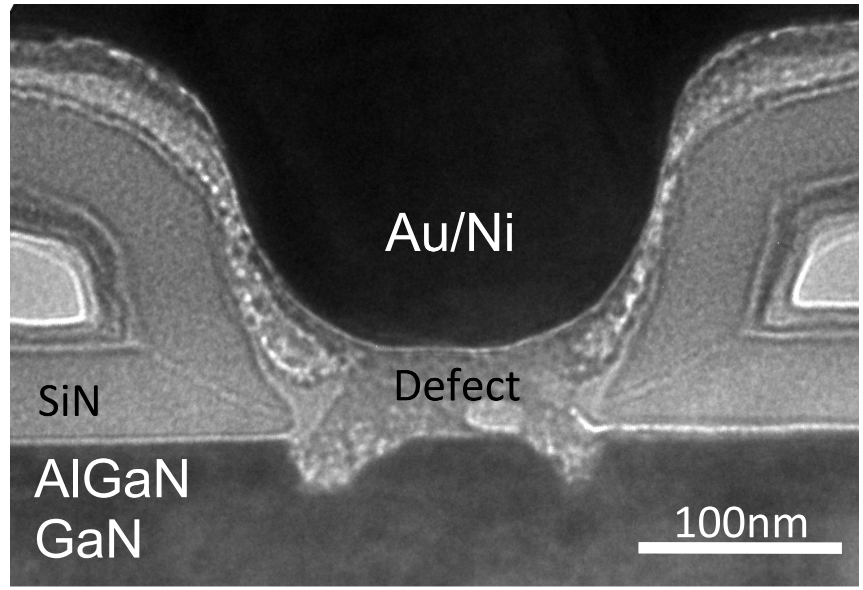
- Large jump in I_G at V_{Crit}

- What characteristic is correlated to defects?

AlGaN Pitting for Pt and Ni Gate HEMTs



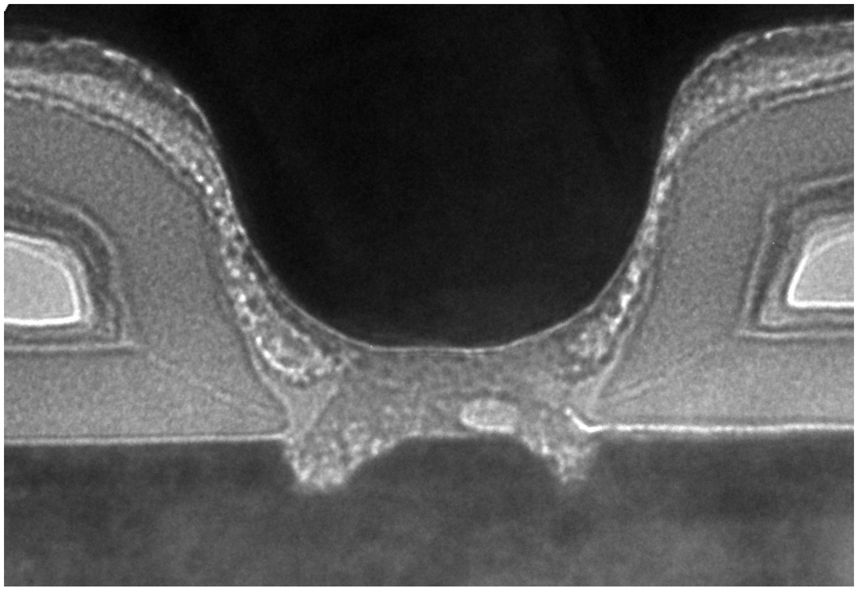
Burnham et. al., PSS C **8**, 2399-2403 (2011)



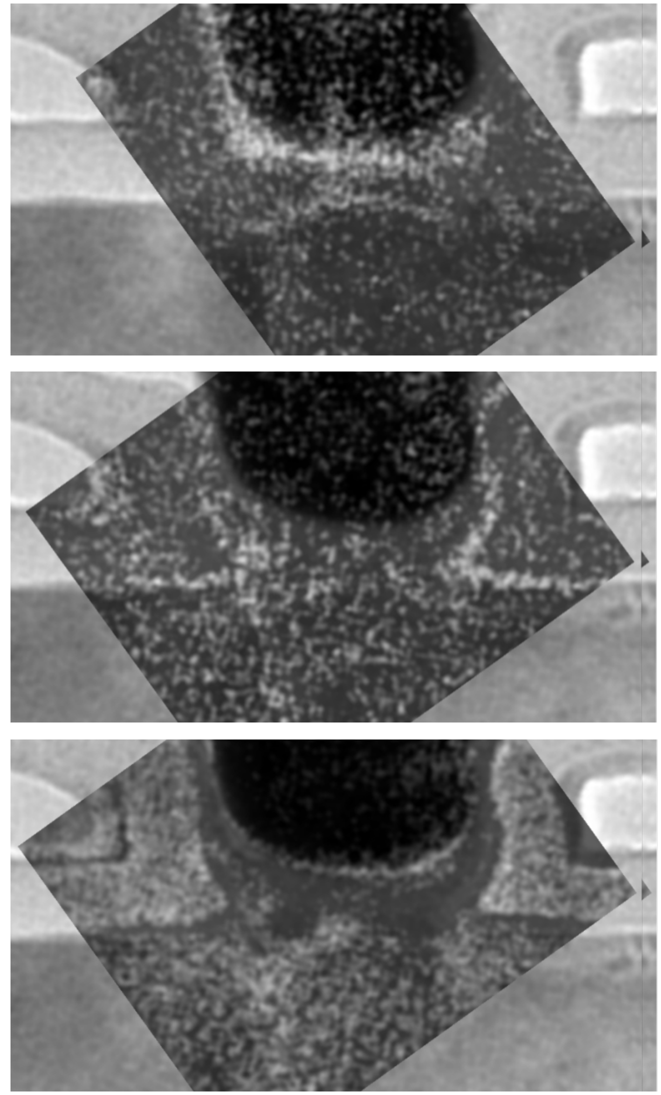
AFRL 1514A post-stress (to be submitted)

- Pitting defects are found in both Pt and Ni-gated HEMTs.
- Large gate leakage correlates to more pitting.

EELS analysis of Pits in AFRL Ni-Gates

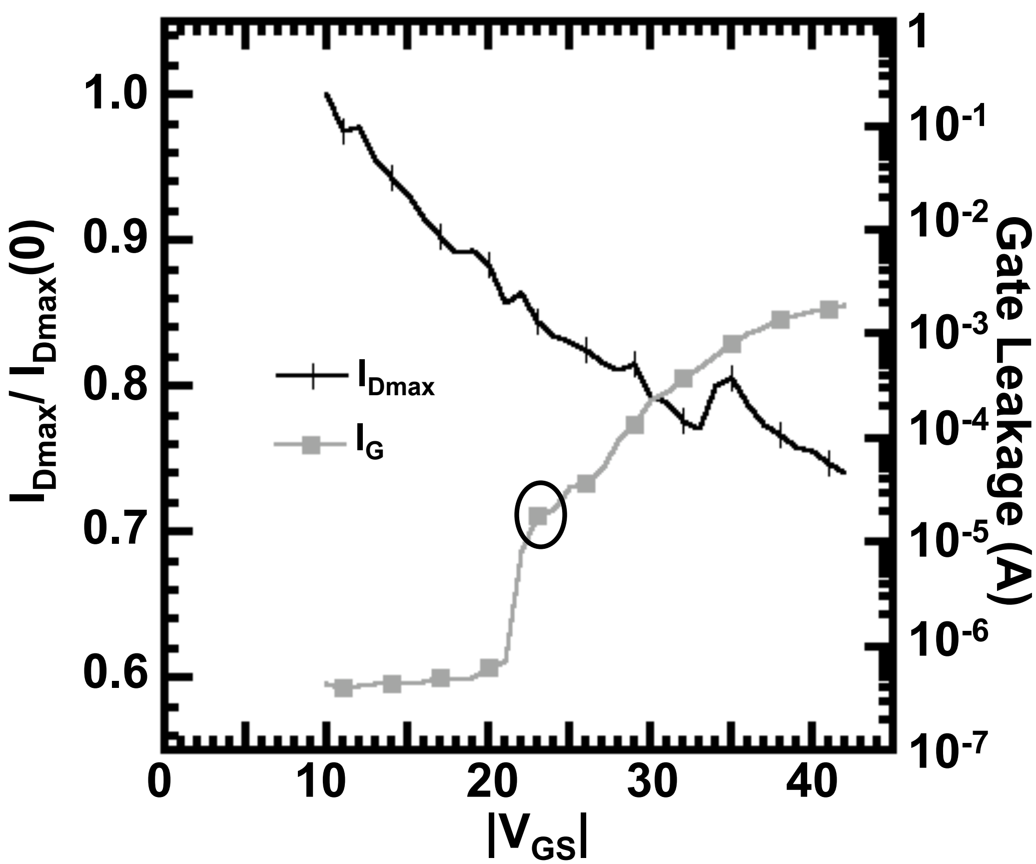


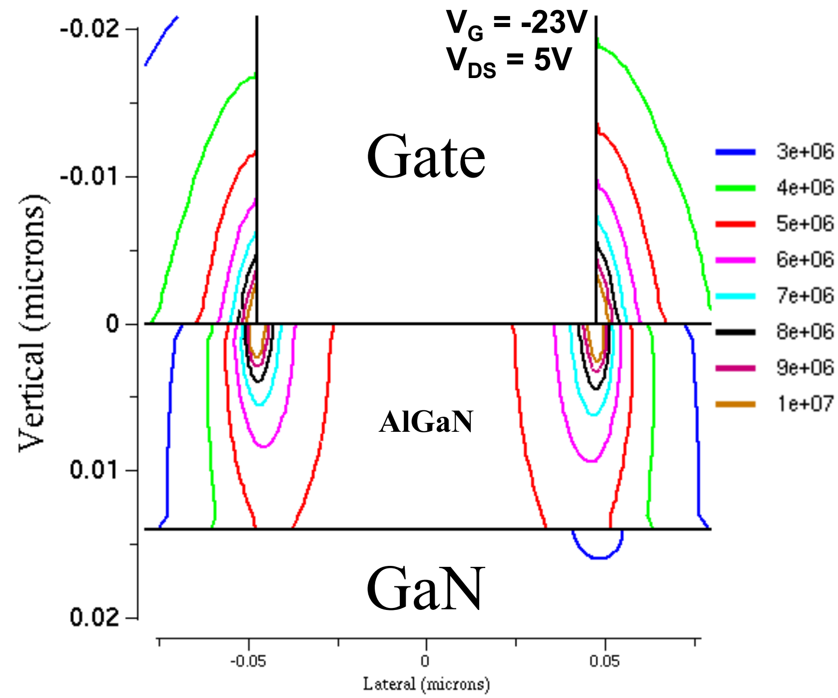
AFRL 1514A post-stress (to be submitted)

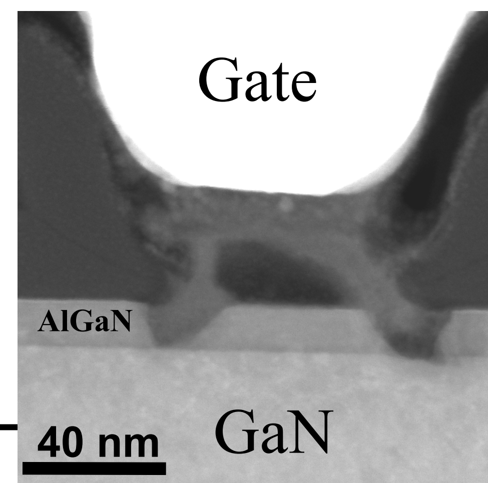


- Pitting defect appears to be some type of Ni-oxide with possible Al and Ga out diffusion from epilayer

Modeling the Field vs Defect Morphology at I_G Jump

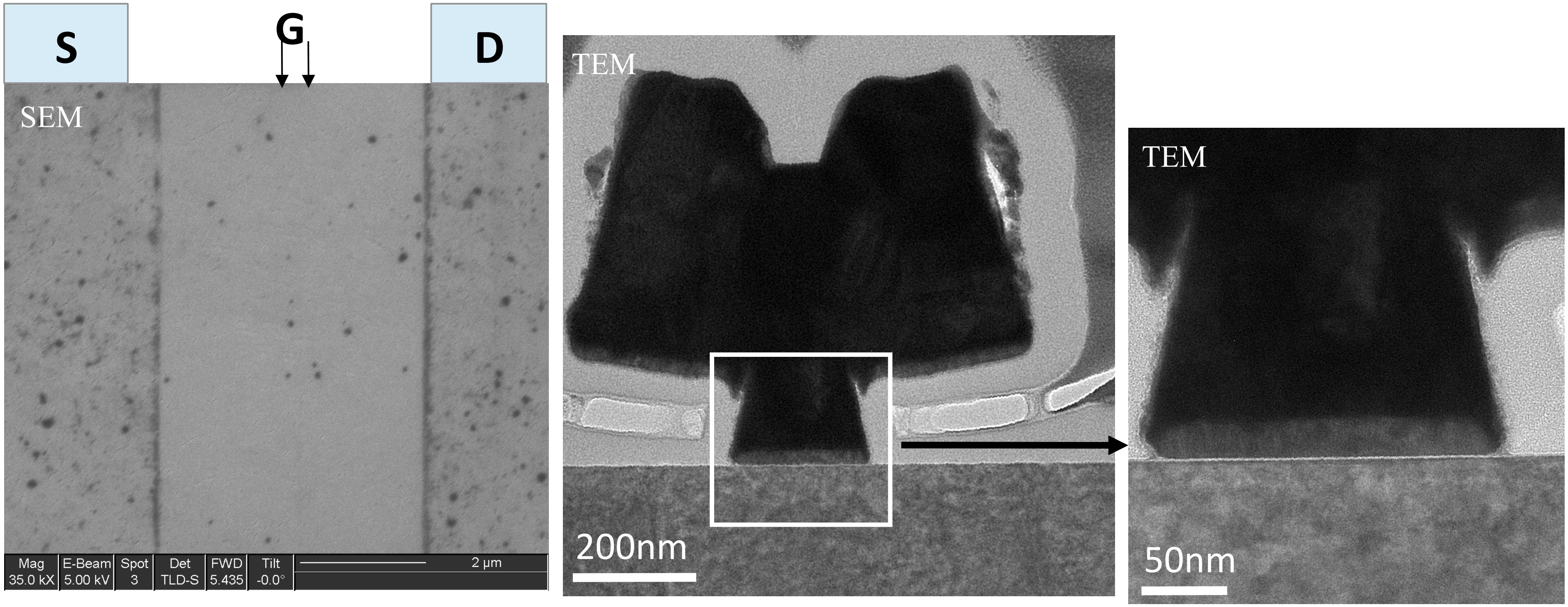






- Shape of defect is similar to Electric/Strain field contours at 5 MV/cm

Effect of Long Term Operating Temperature Anneal



-No apparent degradation after 1000 hr @ 75°C

-Pitting may have dependence on field or current

-Higher temperature anneals needed to replicate degradation

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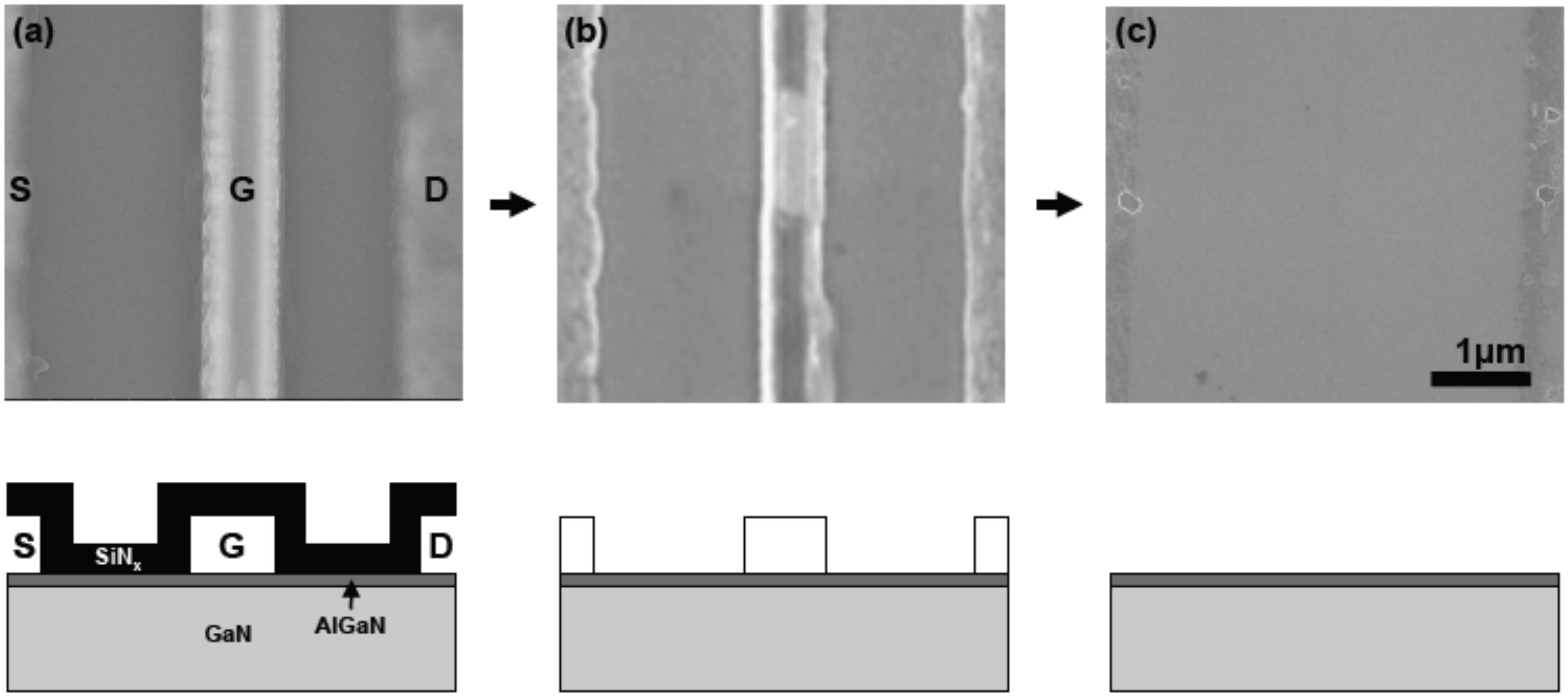
Deprocessing Method

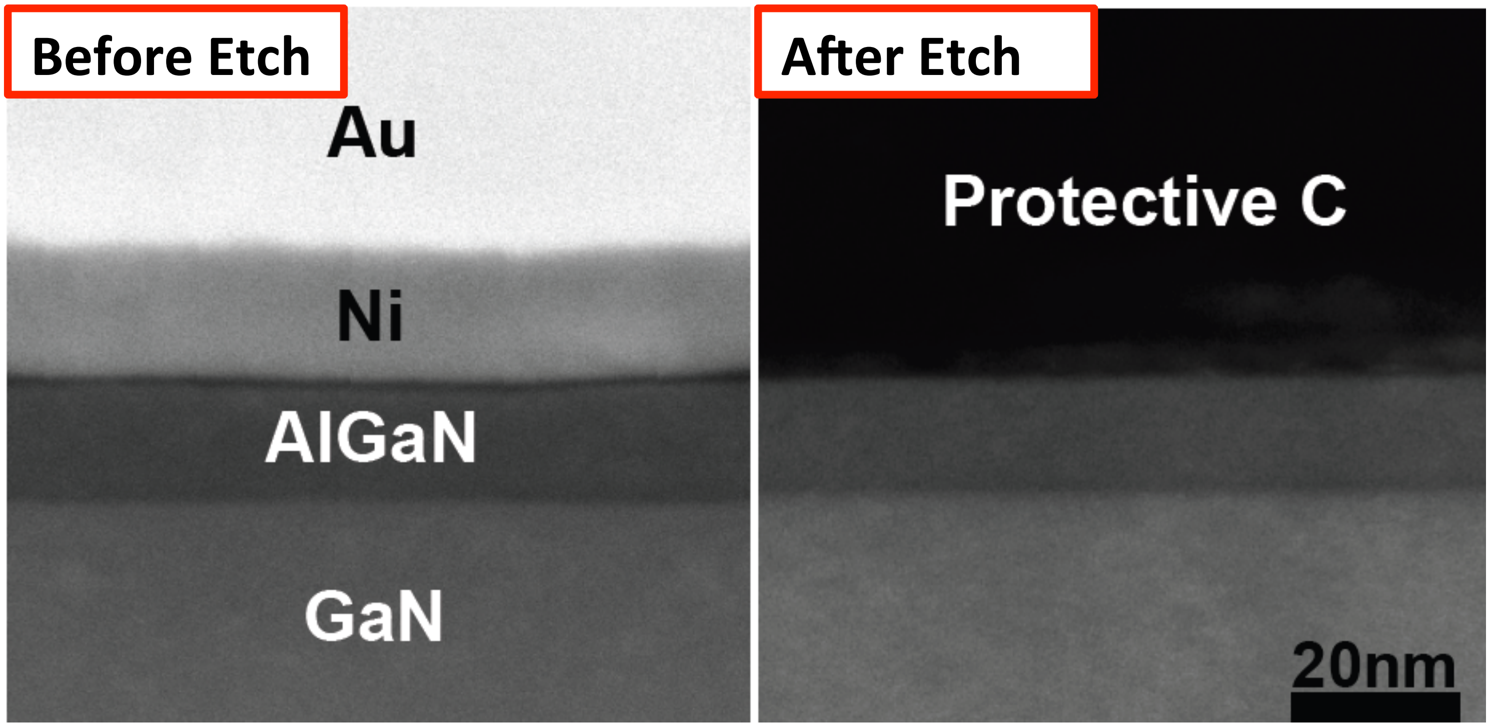


A: HEMT with passivation SiN, Ti/Al/Ni/Au ohmics and Ni gate.

B: HEMT etched for 10 min with BOE to remove passivation SiN.

C: **HEMT etched for 20 hr in FeCN/KI to remove metallization**.

Etch Selectivity



Unstressed **Unstressed**

Deprocessing appears to be very selective!

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Experimental Conditions

- Electrical Stressing
  - Performed at 25°C in ambient
  - V_{DS} = 5V or 10V
  - V_{GS} Variable from V_{GS}= -5 or -10 to -42V

- Thermal Stressing
  - Banding study at 500°C
  - Pitting study in range from 450°C to 850°C
  - No electrical biasing

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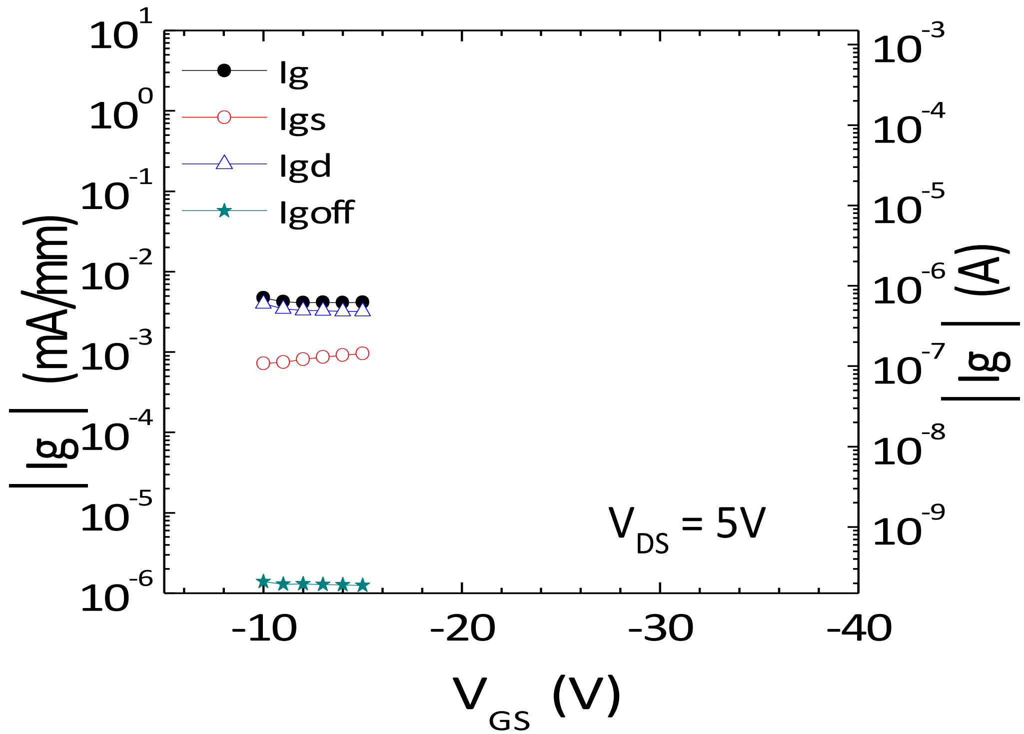
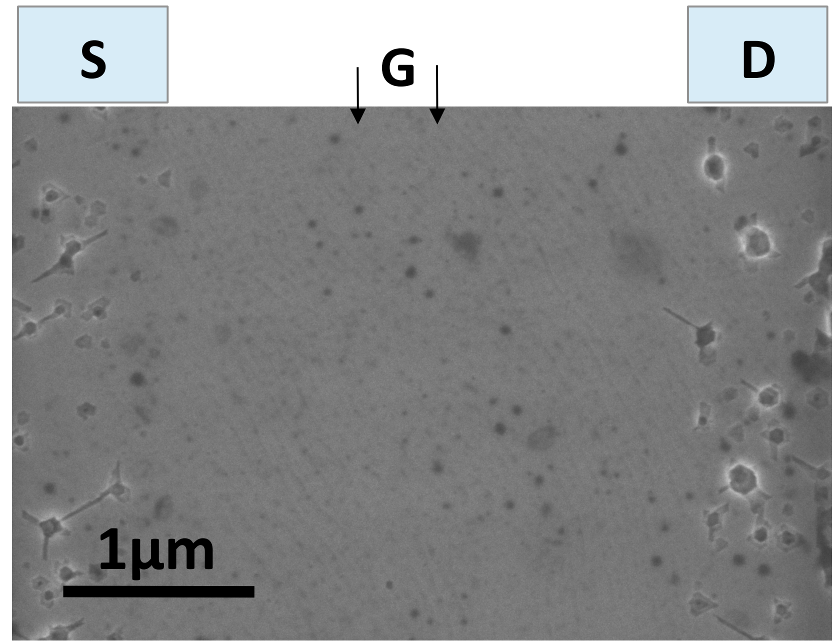
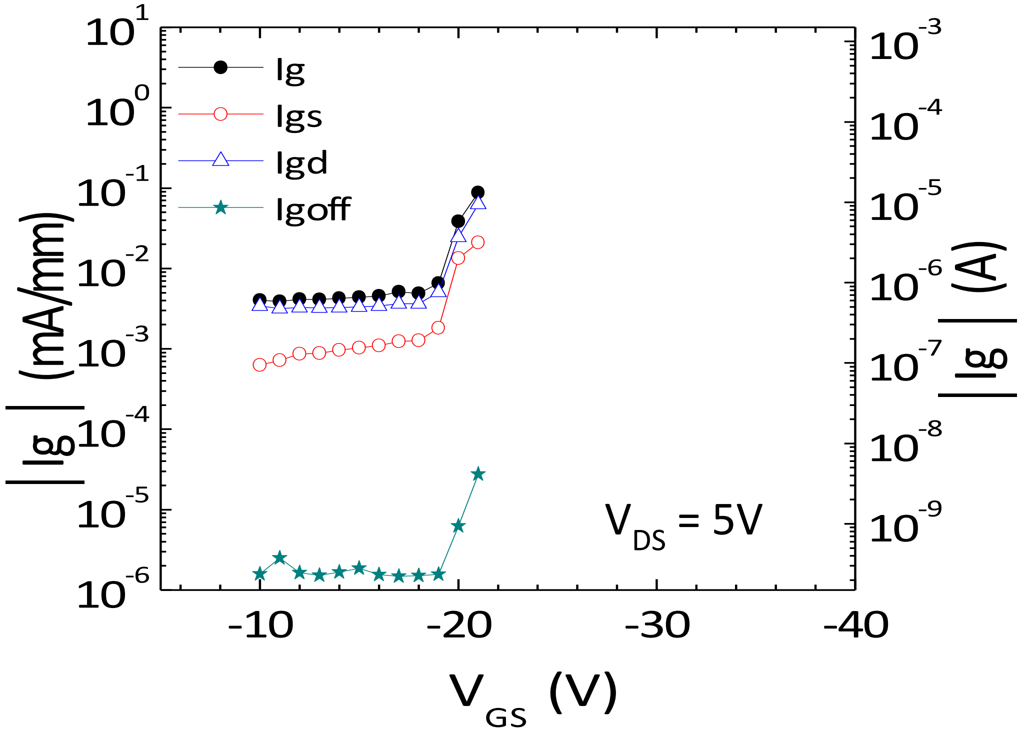
Pristine Surfaces Below V_{CRIT}

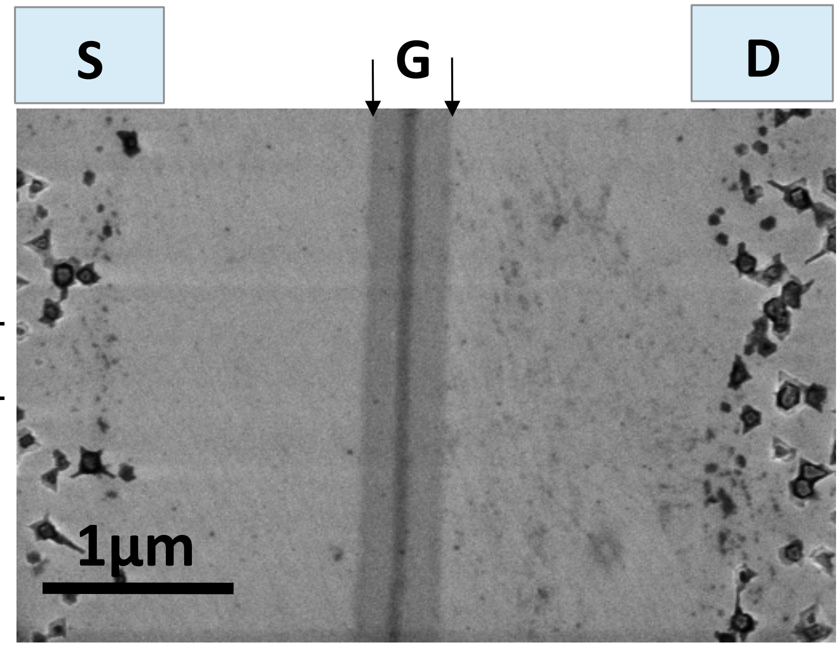




- Stepped stressing from V_{GS}=-5V to V_{GS}=-14V
- No defect formation observed.

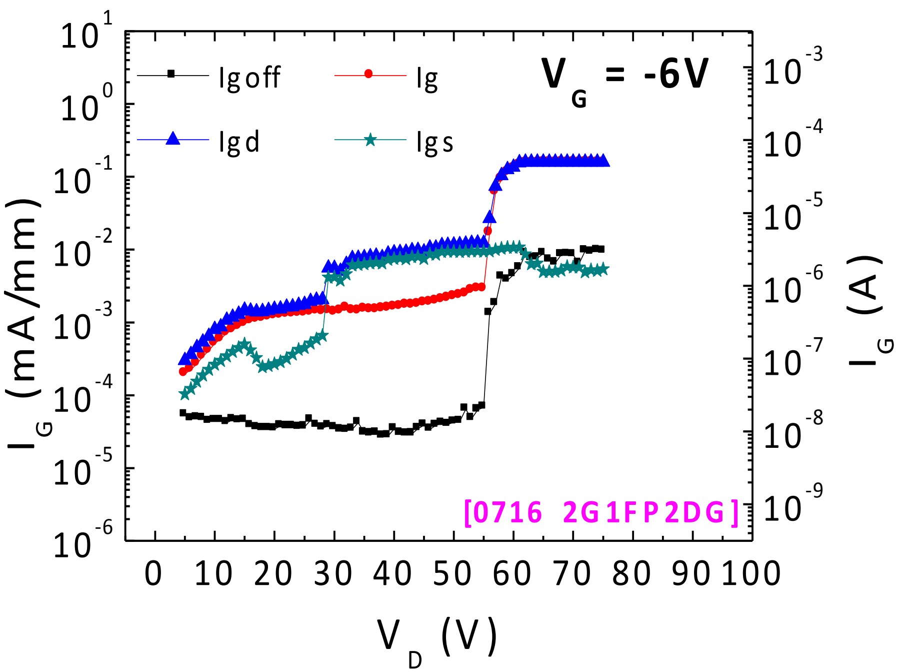
Banding At V_{CRIT}

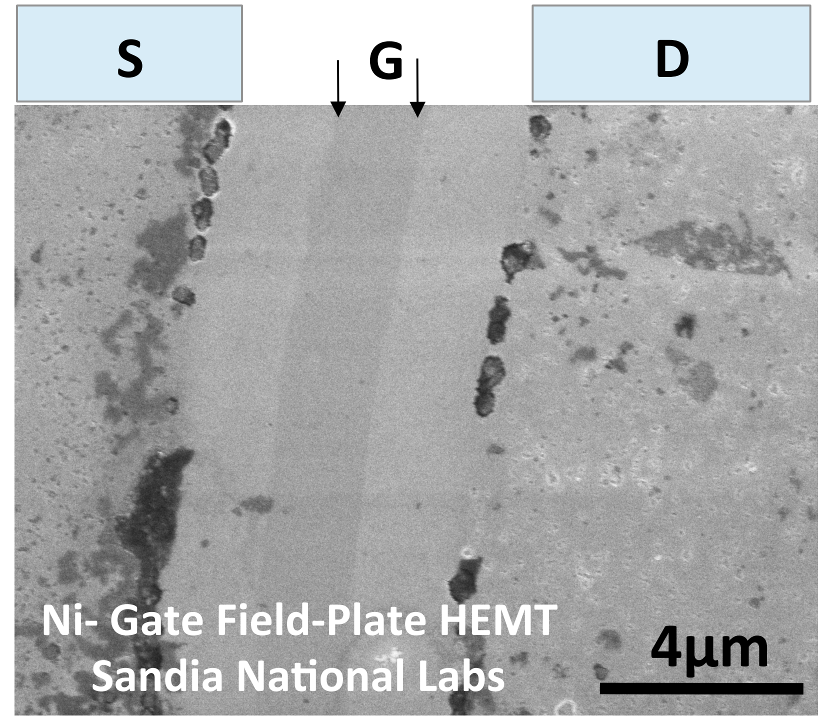




- Stepped stressing from V_{GS}=-5V to V_{GS}=-21V
- “Bandlike” defect observed over 65% of gate.
- Additional etching/cleaning does not remove it.

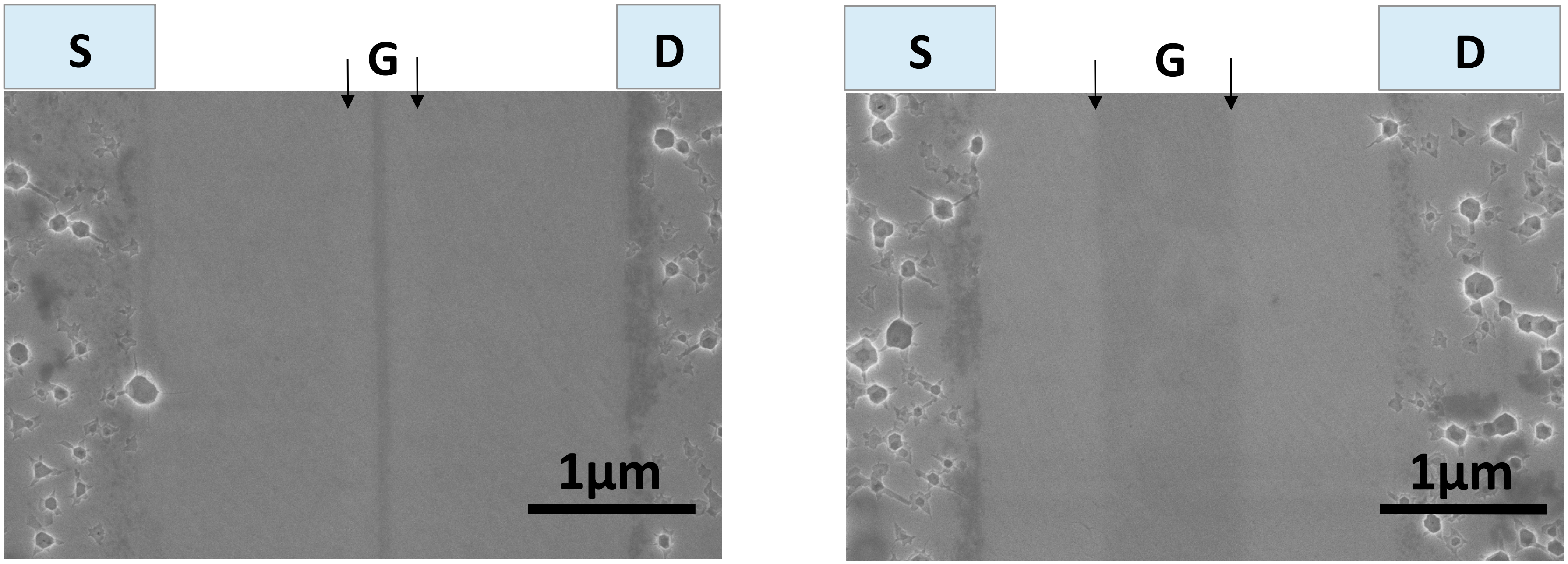
Banding in Micron-Scale Devices





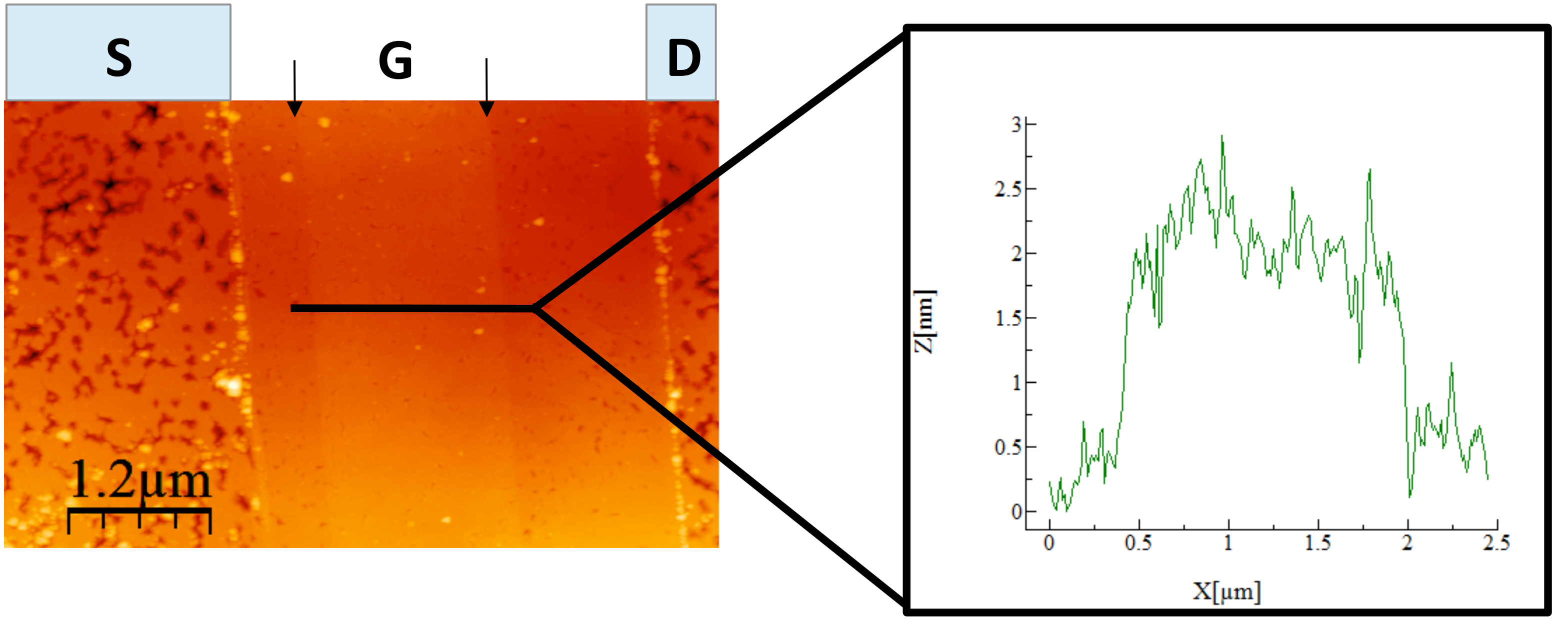
- Banding seen on larger gate devices from Sandia Labs.
- No banding observed on devices biased at V_{DS}=0V.

Thermally-Induced Banding



- Banding is induced by annealing at 500°C.
- Observed over the full gate width after 24hrs.

AFM of Thermally Induced Banding



- Ni Gate HEMT annealed for 6hrs at 500°C.
- AFM indicates:
    - Dark band corresponds to swelling of ~2nm
    - Roughening of ~7Å as compared to 4Å outside of band
- Interdiffusion at interface may be responsible for banding.

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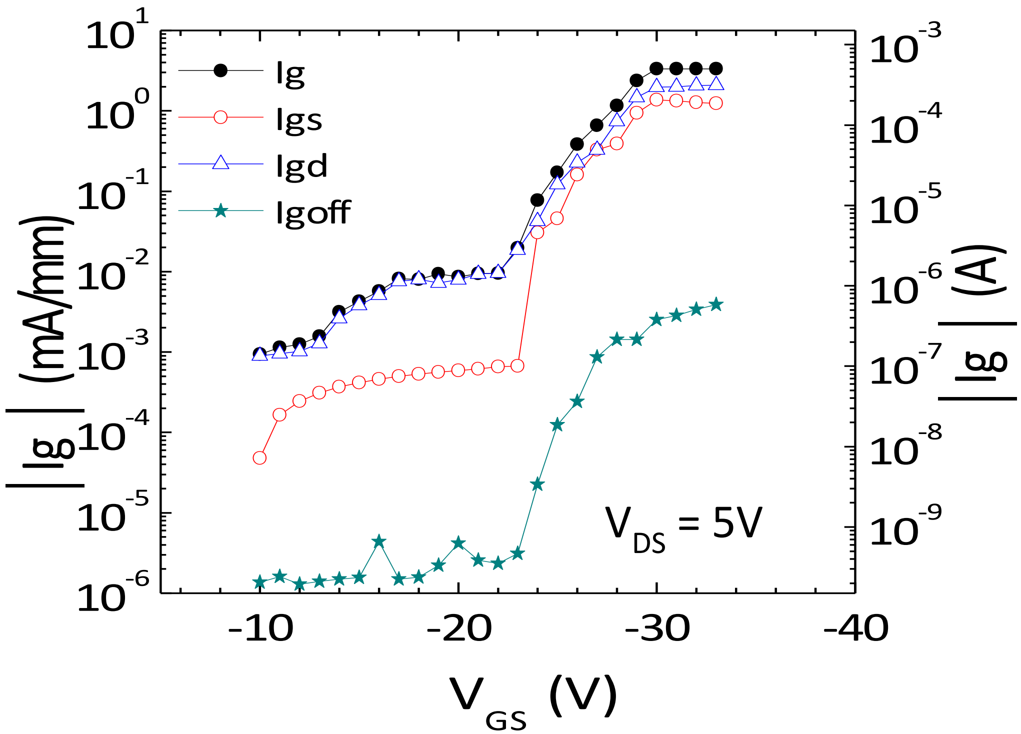
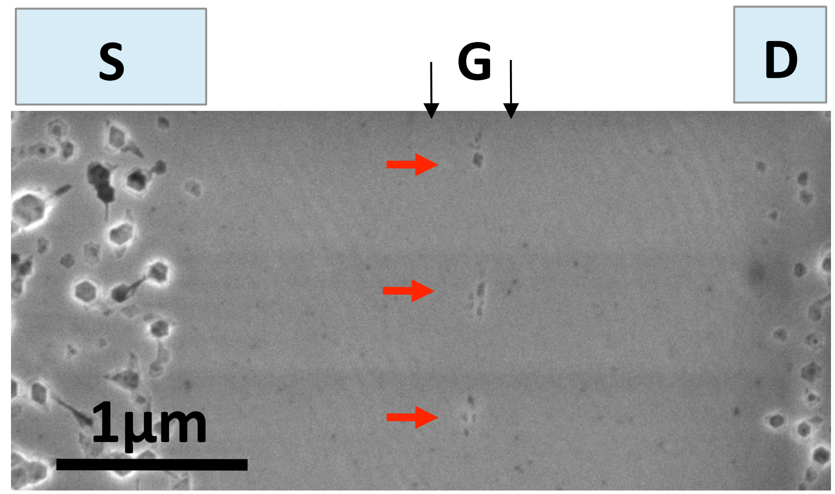
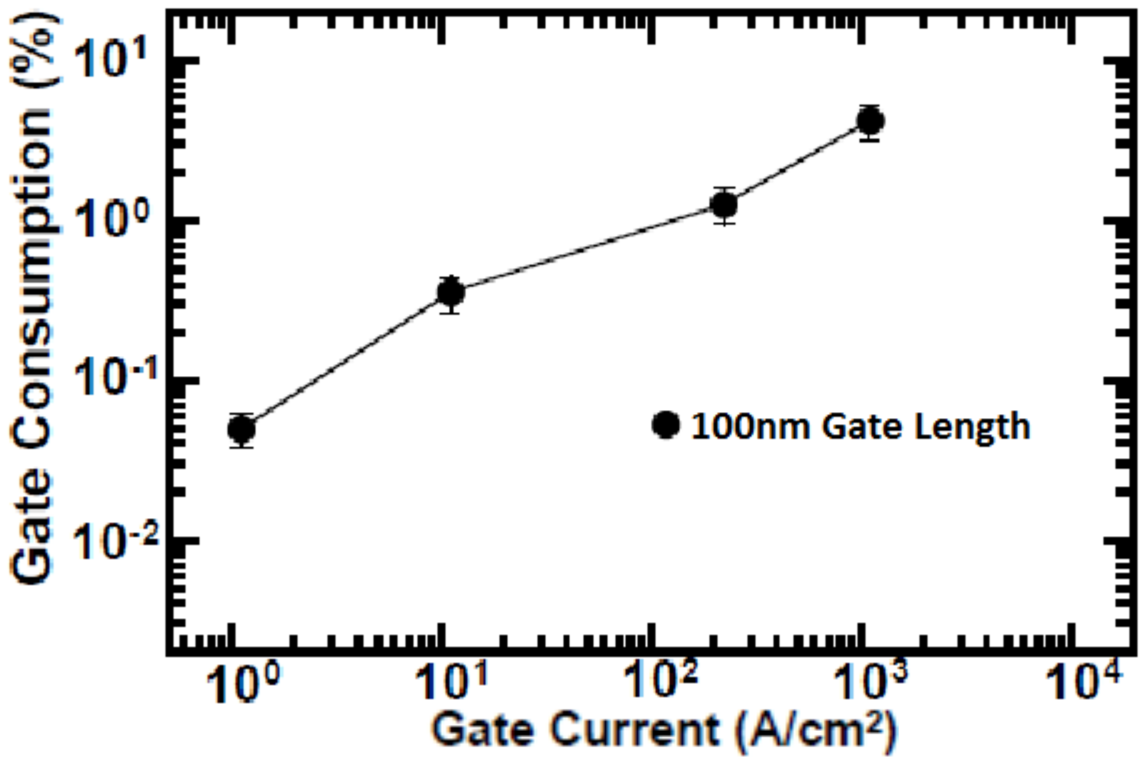
Pitting After V_{CRIT}





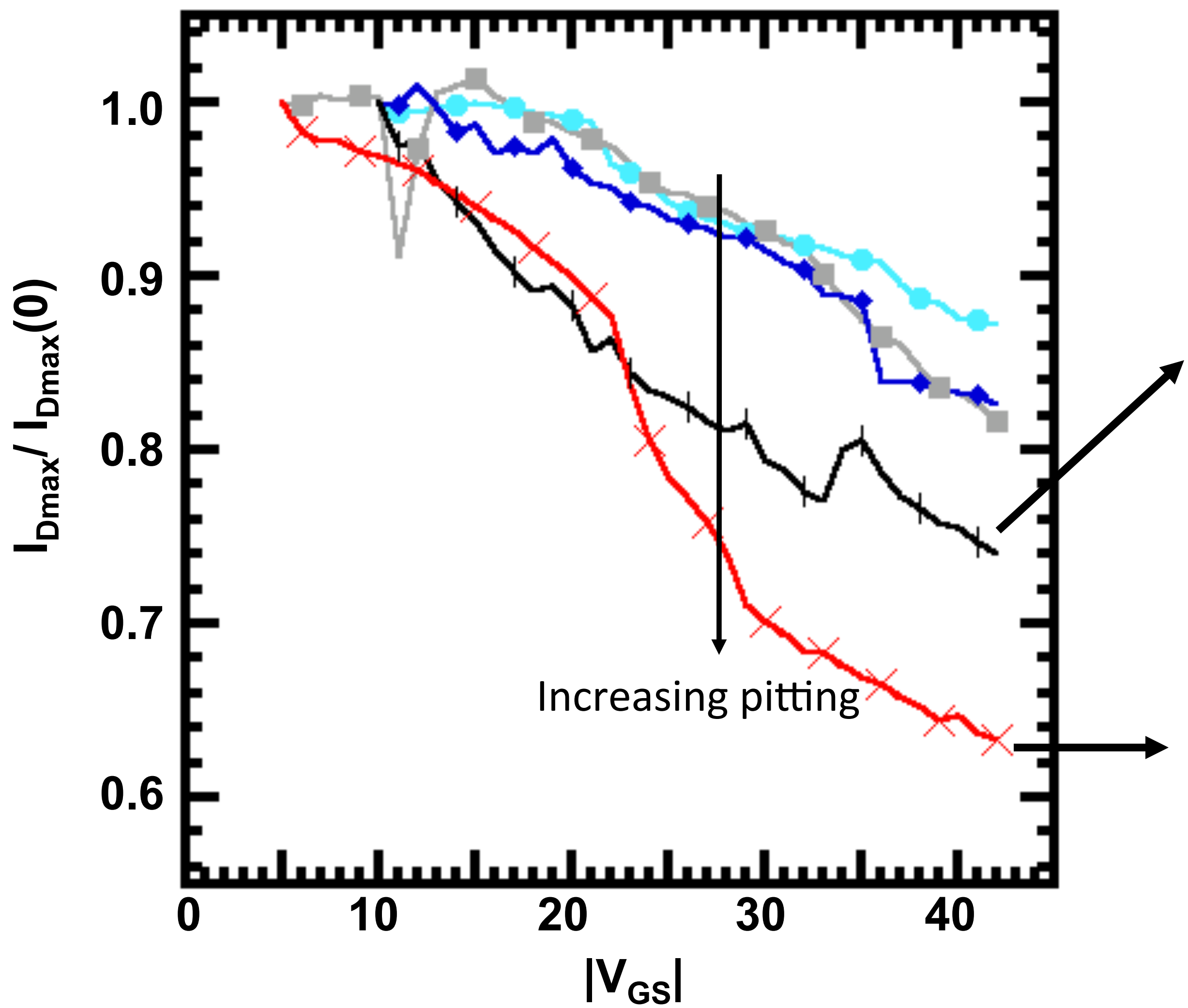
- Stepped stressing from V_{GS}=-5V to V_{GS}=-36V
- Pitting defect observed over 5.5% of gate area.
- Same morphology as previously observed pitting.

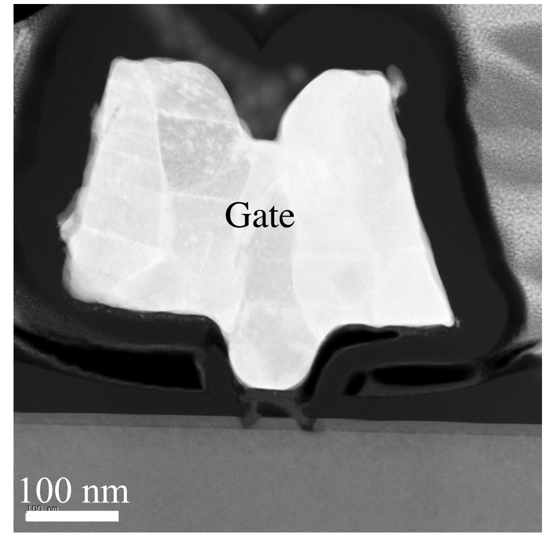
Consumption Influence on I_G

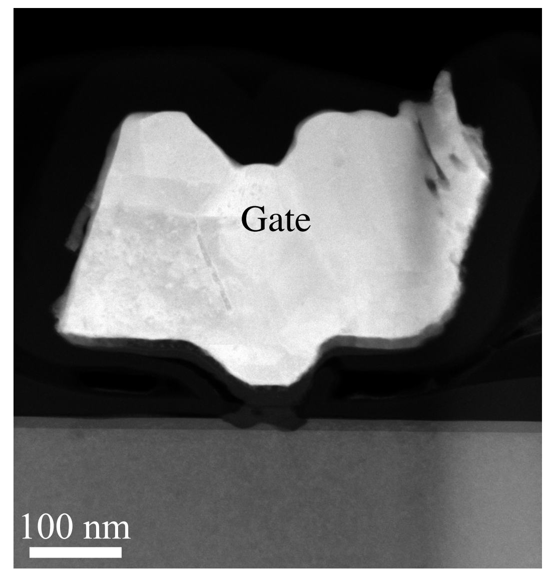


- High gate current densities correspond to large consumption defect densities.

Effect of pitting on I_D







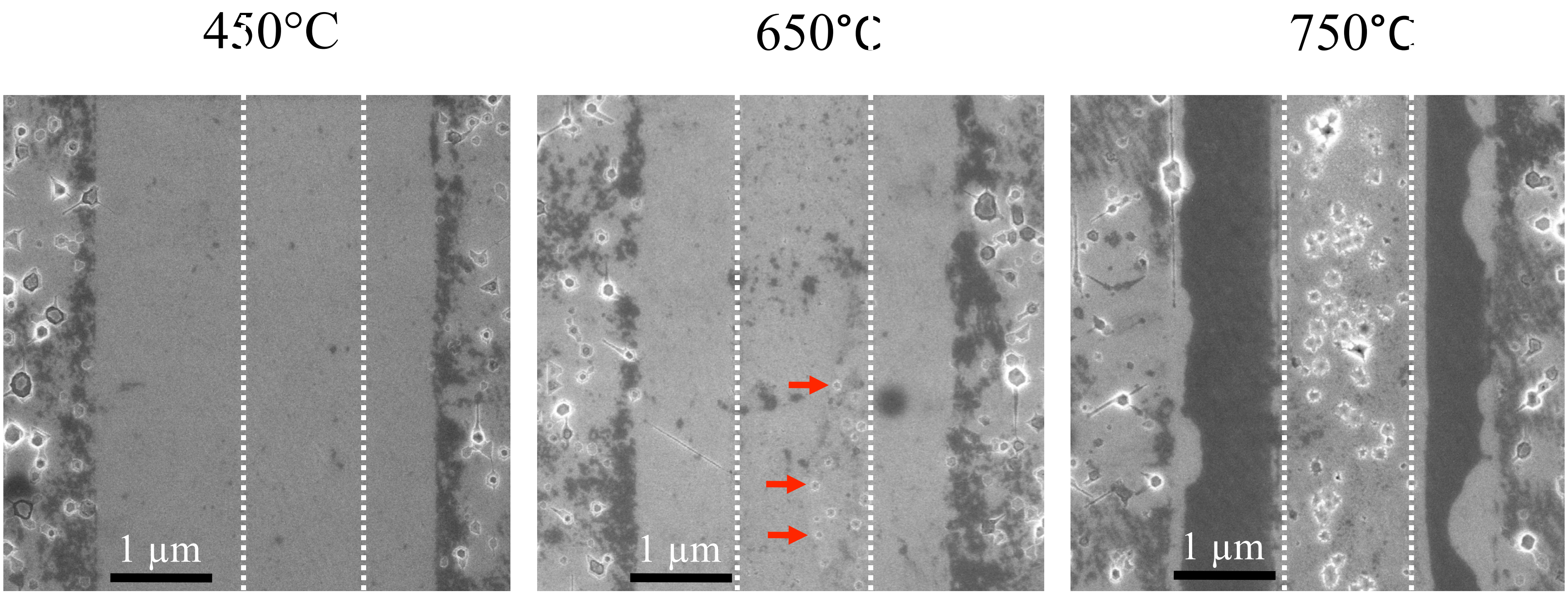
Outline

- Motivation
- Deprocessing Method
- Observed Defects
  - Banding
  - Consumption
    - Electrical
    - **Thermal**
  - Deformation
- Future Work

Thermal Study Motivation

- Electrical defects are difficult to obtain (competing formation mechanisms) and are rarely more than a few % of the gate width
- HEMTs annealed in ambient to recreate previously observed electrical defects with greater frequency
- Determine the role of temperature on degradation

SEM of Iso-Chronal Annealed Samples



-Increased aerial density and size with increasing temperature

-30 min anneals

-By 650°C observation of pitting along threading dislocations

Conclusions

- Pitting and banding defects can be formed with thermal stressing or electrical stressing.
- Banding defects appear near V_{CRIT} and are likely caused by interdiffusion at the AlGaN/Ni interface.
- Pitting defects occur at high gate leakage during electrical stressing and may be initiated by diffusion down threading dislocations during thermal stressing.
- Aerial density and size of dislocation pits increase with anneal temperature

Future Work

•XTEM of the banding defect and dislocation pitting from thermal studies.

•V_{DS}>0 and V_{DS}=0 stressing to determine the dependence of banding on biasing conditions as well as V_{CRIT}.

•Extract activation energy for growth of pits

•Thermal anneals under Ar-H ambient to determine role of oxygen on dislocation reaction.